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Hydrogeology of spoil at three abandoned surface mines in Illinois: preliminary results

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Cover photo: Recreational area at the Coal City study site.

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ABSTRACT

The impact of surface coal mining on the geologic materials and ground water in different geologic settings is under investigation at three abandoned surface mines in Illinois. At a site near Ottawa, the overburden prior to mining consisted largely of pyritic shale; sand was the major component of the overburden and spoil at a mine near Coal City. Clays, lacustrine silts, and some shale and limestone were the predominant premining overburden materials at a mine near Harrisburg. Ground-water elevations at Coal City and Harrisburg are approximately at premining levels, whereas at Ottawa they are near the base of the spoil. Ground-water quality has deteriorated at all three sites, especially at Ottawa and Harrisburg.

INTRODUCTION

Background

Although coal was first surface mined commercially in the United States in 1866, underground mining provided nearly all the coal produced in the nineteenth and early twentieth centuries. The development of large stripping equipment in the early 1900s stimulated the expansion of the surface mining industry. Today, surface mining is a major method of coal extraction. Nearly half of the coal mined in Illinois comes from surface mines; United States coal production from surface and underground mines will undoubtedly increase to meet future energy needs.

The Federal Surface Mining Control and Reclamation Act was enacted in 1977 with the intent to minimize the deleterious effects of mining on the environment. The act specifically requires a characterization of the hydrogeology of any mine site and an assessment of the hydrologic conditions expected after mining and reclamation. Although no mining permit can be approved without this information, hydrogeologic data are sparse regarding the impact of surface mining on ground water in flat, glaciated terrains such as are common throughout Illinois.

Previous work

From 1955 to 1966, the U.S. Geological Survey compared surface-water and ground-water conditions in mined and unmined drainage basins in southeastern Kentucky (Collier, Pickering, and Musser, 1970). Changes caused by surface

mining included increases in acidity and mineralization in surface and ground water and an increase in sedimentation in the mined watershed. Ground-water levels in the spoil appeared to stabilize relatively quickly after mining stopped. Mezga (1973) investigated the changes caused by surface mining in the surface-water and ground-water hydrology of a small watershed in Ohio. The spoil, consisting largely of weathered shale, had an average porosity of 44 percent and an average hydraulic conductivity of 4.1×10^{-3}cm/sec. The ground-water velocity was calculated to be 1.7 m (5.5 ft) per day. During the past several years, researchers at Iowa State University have monitored ground-water conditions during and after mining and reclamation at a small surface mine in Iowa. Preliminary data suggested that the spoil, which was largely glacial till and shale, was slowly becoming saturated with water (Sendlein and Stangl, 1977).

In western Illinois (Fulton County), the Metropolitan Sanitary District of Greater Chicago studied surficial materials and ground-water quality in strip-mined and unmined land in the early 1970s before establishing a sludge disposal program. The pH of the mine spoil averaged 7.4, whereas the samples from undisturbed lands averaged 6.5; the spoil generally showed higher electrical conductivity values than the samples from the undisturbed land (Peterson and Papp-Vary, 1972). A comparison of ground water from mined and unmined sites suggested that ground-water quality deteriorated because of mining. The quality of the ground water in the mine spoil varied greatly as a result of the heterogeneous chemical and physical character of the spoil (Pietz, Peterson, and Lue-Hing, 1974).

Argonne National Laboratory also has investigated the impact of a gob pile on ground water in southern Illinois. The site is underlain by calcareous, silty clay till. Shallow ground water around the gob pile (within 120 m) is generally low in pH and has high concentrations of dissolved metals and sulfate. Beyond 120 m (400 ft), water quality improved significantly (Schubert, Olsen, and Zellmer, 1978; and Schubert, 1979).

Haynes and Klimstra (1975a, 1975b) inventoried surface-mined lands in Illinois and determined some physical and chemical properties of selected spoil materials; however, no correlation was made with the original overburden geology. Acidic spoil was found to occur in all areas of surface-mined land in the state.

A number of studies have provided useful information regarding the hydrology of surface mines in the Midwest; however, we need a better understanding of the interactions between mine spoil and ground water in different geologic environments to allow evaluation of the hydrogeologic consequences of future surface mining. Because surface mining will continue to be a major method for extracting coal, and because data on the hydrogeologic impacts of surface mining in flat, glaciated terrain are sparse, the Illinois State Geological Survey began in 1977 a long-term study to generate these data. Although the study concerns Illinois surface mines only, the variety of geologic environments in Illinois can provide information applicable to many other parts of the country.

Objectives

The original study had four objectives:

(1) To characterize the physical and chemical properties of mine spoil.

(2) To determine the effect of mining on ground water by comparing conditions in unmined areas with those in adjacent mined areas. (Hydrogeologic and geochemical conditions were examined in both the saturated and unsaturated zones.)

(3) To examine and compare mine spoil and ground-water conditions in different geologic settings.

(4) To develop a method for evaluating the hydrogeologic consequences of surface mining.

Site selection

Three abandoned surface mines have been selected and instrumented to date. Two sites are in northern Illinois—one near Ottawa and one near Coal City—and the third is near Harrisburg in southern Illinois (fig. 1). The three study areas have not been mined since the 1940s or early 1950s. The Survey began its work at the Ottawa site in 1977, at the Coal City site in 1978, and at the Harrisburg site in 1979. Each site has a different type of overburden. At Ottawa, the overburden consisted largely of pyritic shale, whereas sand was the major component of the overburden and spoil at Coal City, and lacustrine silts and clay were predominant at the Harrisburg site.

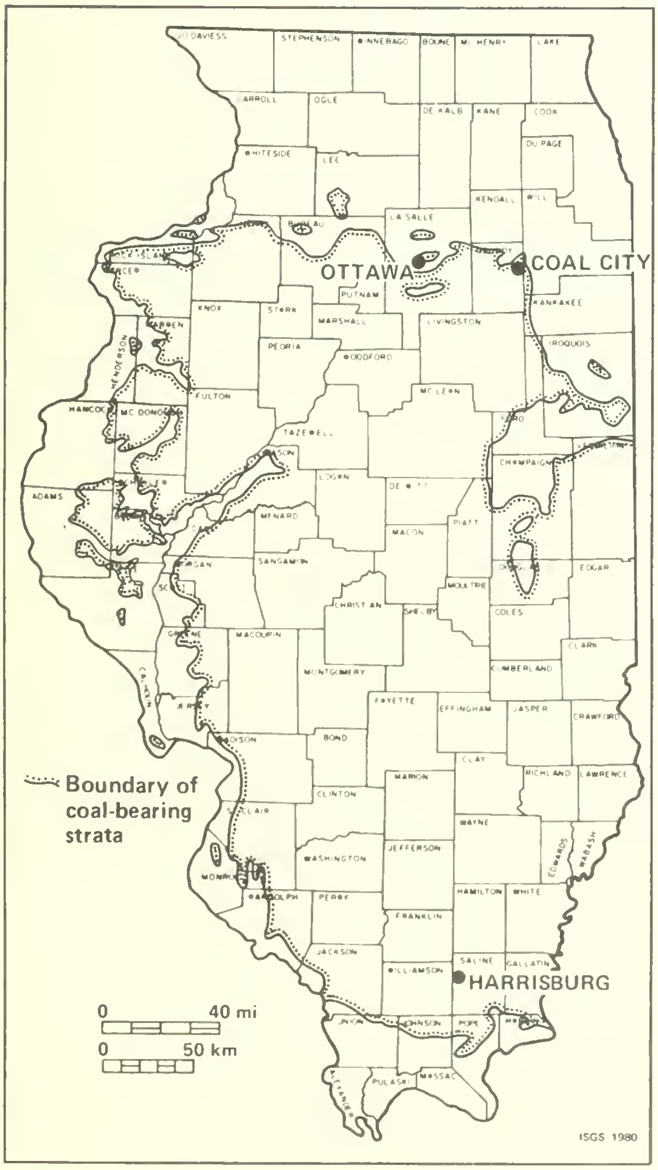

FIGURE 1. Locations of study areas at Ottawa, Coal City, and Harrisburg.

OTTAWA STUDY AREA

Geology

The Ottawa study area sits on an upland at the edge of a bluff overlooking the Illinois River and is approximately 9 km (6 mi) west of Ottawa in La Salle County (fig. 2). The Osage Coal Company mined the area in the late 1930s; the mine was abandoned in 1949. The coal mined at this site was the Colchester (No. 2) Coal Member, which is equivalent to the Colchester Coal Member (IIIa) in Indiana and the Schultztown Coal in Kentucky (fig. 3).

The premining overburden measured 3 to 8 m (10 to 25 ft) thick and consisted chiefly of gray shale (Francis Creek Shale Member); pyrite was common in the lower 1.5 m (5 ft). Up to 3 m (10 ft) of loess and glacial till

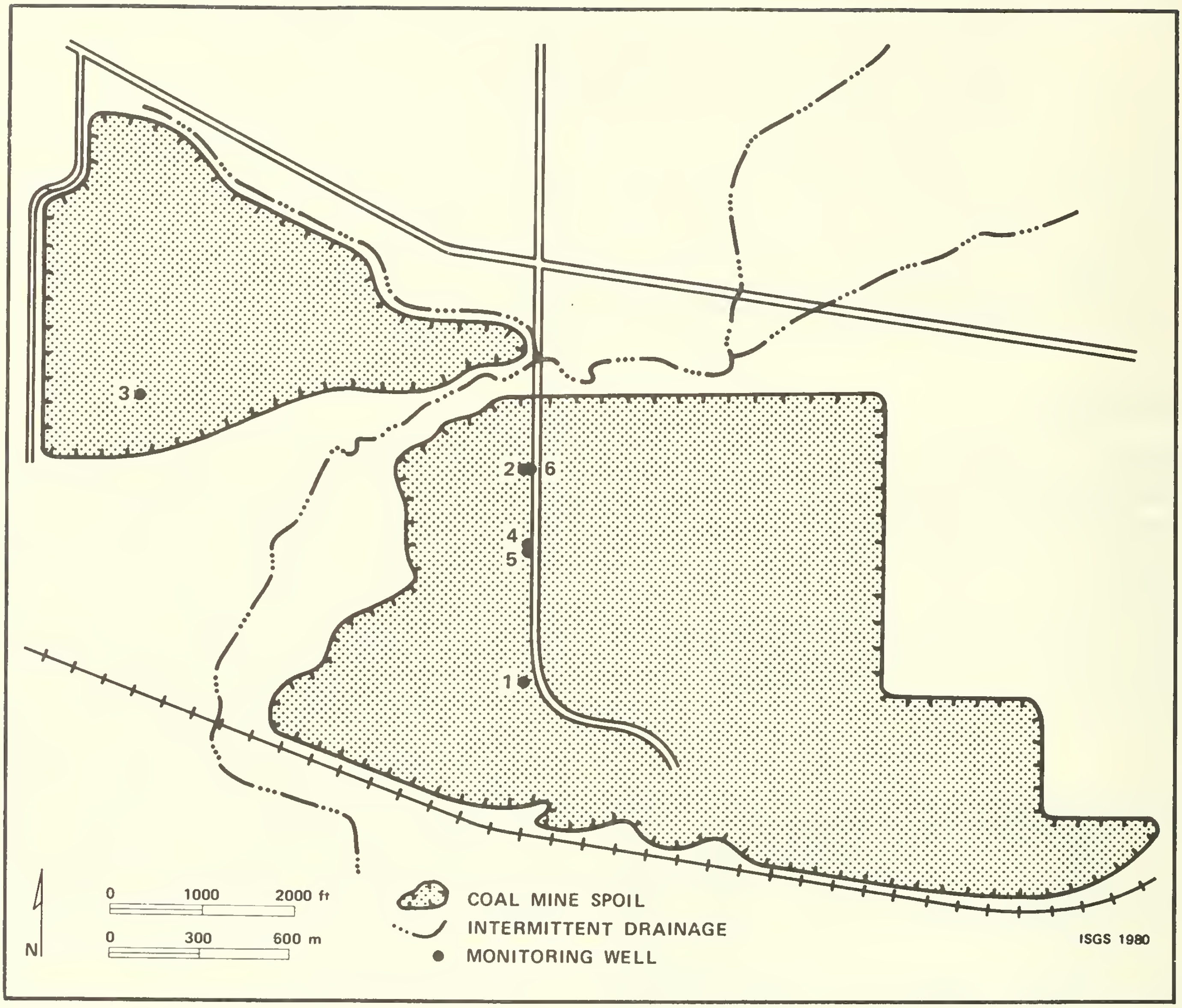

FIGURE 2. Locations of monitoring wells and instruments at Ottawa study area, La Salle County (Secs. 11, 12, 13, and 14, T. 33 N., R. 2 E.).

overlay the shale. The No. 2 Coal was pyritic and measured 0.5 m (22 in.) thick (Smith, 1968). The underclay beneath the coal is less than 1.5 m (5 ft) thick and overlies the St. Peter Sandstone (Ordovician). In some areas the underclay was reportedly removed for brick making. The St. Peter is about 40 m (140 ft) thick and is a significant aquifer regionally (William and Payne, 1942).

The Pennsylvanian bedrock at Ottawa is unusually thin because of its proximity to the La Salle Anticlinal Belt, which lies just to the west. The La Salle Anticlinal Belt is a series of anticlines, synclines, and domes extending from La Salle County in north-central Illinois to Lawrence County in southeastern Illinois (Atherton and Palmer, 1979). Bedrock on the east side of the anticline has been uplifted relative to bedrock to the west and eroded. The thick succession of Silurian, Devonian, and Mississippian carbonate and shale units, which separates the St. Peter Sandstone and the Pennsylvanian elsewhere in the state, has been completely removed by erosion in the Ottawa area (fig. 4).

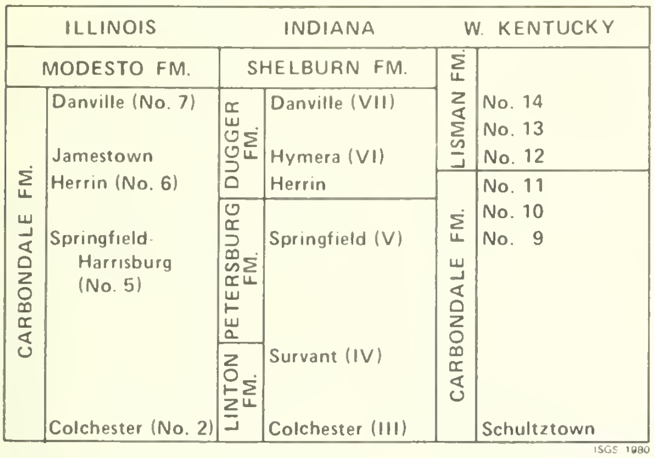

FIGURE 3. Stratigraphic correlation of the Carbondale Formation in Illinois. (After Coal Section Staff [ISGS], 1978.)

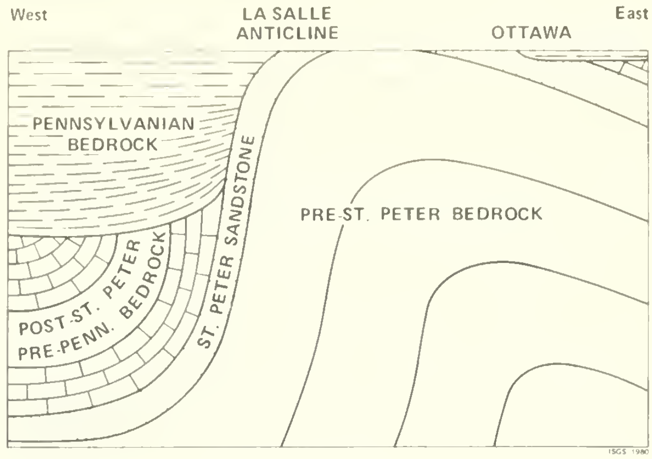

FIGURE 4. Idealized cross section of La Salle Anticline near Ottawa. (Modified from Willman and others, 1967.)

The spoil at the Ottawa site is 9 to 14 m (30 to 45 ft) thick and derived primarily from shale and till. Pyrite is abundant on the surface. The spoil is gray to dark gray and ranges from a silty clay to a silty clay loam.

The site is a barren landscape consisting of mounds of spoil emplaced during mining (fig. 5). No reclamation effort was made. The vegetation is sparse, probably because the spoil is acidic. Analyses of more than 100 spoil samples by the Illinois Department of Transportation gave pH values ranging from 2.3 to 7.9 and a mean of 4.9. The high acidity probably was caused by the weathering of pyrite; weathering products have also formed a thin crust on top of the spoil, which has limited the infiltration of precipitation.

Ground water

Six wells were drilled to the base of the spoil to allow sampling of ground water and observation of fluctuations of water level in the spoil. Tensiometers and suction lysimeters were installed in the unsaturated zone of the spoil (fig. 2).

Water levels, as measured in the wells, are near the base of the spoil. Two of the wells have never yielded water, and a third has yielded it only sporadically. The static water levels are unusually low for material of low permeability; ground-water levels in fine-grained materials in Illinois are typically within 3 m (10 ft) of the surface. Two factors appear responsible for these abnormally low levels: (1) The thin crust formed on the surface of the spoil reduces infiltration. Precipitation entering the site leaves mostly by runoff and evaporation. (2) The upper 15 m (50 ft) of the St. Peter Sandstone, which underlies the spoil and underclay, is unsaturated and drains ground water from the overlying spoil. Only the underclay and a zone of iron-cemented sandstone below the underclay prevent the complete drainage of the spoil by retarding downward ground-water movement. Because these materials

FIGURE 5. Barren landscape at Ottawa study area.

have low hydraulic conductivities, the static ground-water level is "held up" or perched near the base of the spoil (fig. 6).

Ground water is acidic in both the saturated and unsaturated zones (table 1). The pH of water ranges from 3.6 to 6 in the unsaturated zone and from 6 to 6.7 in the saturated zone. The water is highly mineralized—concentrations of total dissolved solids (TDS) exceed 3,800 mg/L in both the saturated and the unsaturated zone. Calcium (Ca), magnesium (Mg), and iron (Fe) are the predominant cations, whereas sulfate (SO_4) is the predominant anion.

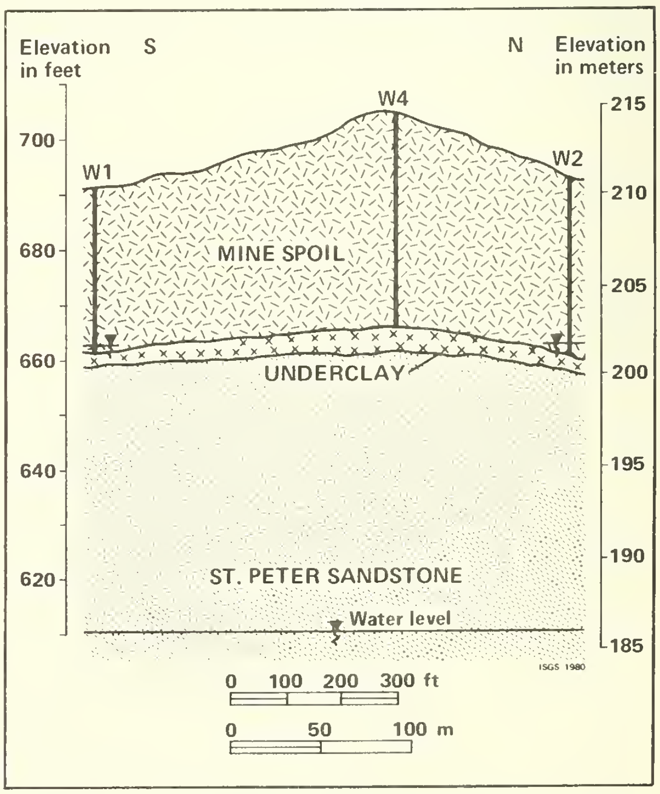

FIGURE 6. Cross section of Ottawa study area showing relationships of the stratigraphy and ground water.

COAL CITY STUDY AREA

Geology

The Coal City site is about 55 km (35 mi) east of the Ottawa site, in

TABLE 1. Water quality data for Ottawa study area

Sampling point	Date sampled	T (°C)	pH	EC (µmhos/cm)	TDS (mg/L)	Alk (mg/L)	Hard (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Al (mg/L)	Ca (mg/L)	Fe (mg/L)	K (mg/L)	Mg (mg/L)	Mn (mg/L)	Na (mg/L)	Cu (mg/L)	Ni (mg/L)	Cr (mg/L)	Pb (mg/L)	Zn (mg/L)	Cd (mg/L)
Well 1	5-01-79	14.7	6.48	3,400	3,872	379	2,990	2,460	7	.8	590	12	16	350	26	9	.06	.55	<.17	.18	2.8	<.01
Well 2	5-01-79	16.3	6.48	3,800	4,605	373	3,312	2,860	11	.59	540	88	13	430	17	11	<.03	.58	<.17	<.12	1.6	<.01
Well 3	5-01-79	15.0	6.05	4,000	5,527	206	4,207	3,750	8	.27	400	51	10	750	14	11	.05	.24	<.17	<.12	2.4	<.01
Well 6	5-01-79	16.3	6.05	4,000	5,251	54	3,362	3,280	112	.23	460	410	24	350	17	75	.03	.21	<.17	<.12	4.7	<.01
Lys 2	5-01-79	NM	4.9	*	*	*	109	*	*	380	430	1,030	30	1,550	110	1,090	.05	7.4	<.17	.19	12	.07
Lys 3	5-01-79	NM	5.85	*	*	*	8,092	*	*	.99	430	1,440	17	1,040	81	180	<.03	3.5	<.17	.17	3.9	<.01
Lys 3	9-24-79	NM	NM	NM	11,000	*	6,030	*	*	5.0	344	980	19.6	796	61	370	.45	2.7	.06	<.8	3.39	.09
Well 2	5-19-80	17.2	6.0	*	*	*	*	*	*	.3	470	111	13.3	366	9.7	103	.02	.7	<.05	<.1	1.31	7
Lys 3	5-19-80	17.2	3.6	*	*	*	*	*	*	5.6	324	503	16.1	633	34.8	411	.1	1.8	<.05	<.1	2.36	<3

*Insufficient sample for analysis
NM = not measured

a different geologic setting. Sand is the predominant spoil material. Northern Illinois Coal Corporation mined in this portion of Grundy County in the 1930s and completed surface mining in 1946. The Colchester (No. 2) Coal Member was mined in the study area in the early 1940s.

Before mining, an aeolian sand ridge extended across the study area. Sand to depths of 4.5 to 8 m (15 to 25 ft) overlay up to 3 m (10 ft) of fine-grained glacial drift which in turn overlay up to 4 m (15 ft) of Pennsylvanian shale and sandstone (Francis Creek Shale Member); the bedrock contained little visible pyrite. The No. 2 Coal measured up to 1 m (3 ft) thick and contained small amounts of pyrite. Beneath the coal, a thin underclay overlies about 15 m (50 ft) of Pennsylvanian shale and sandstone (Culver, 1922). Unlike the Ottawa site, more than 130 m (400 ft) of carbonate rocks and shale separate the base of the No. 2 Coal and the top of the St. Peter Sandstone at Coal City.

The spoil at Coal City is 12 to 18 m (40 to 60 ft) thick and consists largely of medium sand. Little gravel or fine-grained sediment is mixed with the sand. The relatively small amount of fine-grained spoil was derived from lacustrine silts and clays, glacial till, and shale. There is little evidence of the acidic (pyritic) spoil that is present at Ottawa.

Although the mine spoil was not reclaimed, vegetation covers most of the site, in sharp contrast to the barrenness of the spoil at Ottawa (fig. 7). In addition, numerous lakes have formed in the spoil, and the area has been converted to recreational uses.

FIGURE 7. Recreational area at the Coal City study site. Although the mine spoil was not reclaimed, vegetation covers the area.

Ground water

Monitoring wells, lysimeters, and tensiometers were installed to determine the ground-water conditions in the spoil (fig. 8). Three staff gauges were placed in lakes formed in the spoil. As already noted, the spoil overlies a thick succession of fine-grained rocks that have low hydraulic conductivities. Unlike the St. Peter Sandstone at Ottawa, these fine-grained sediments retard the downward movement of ground water; this results in the saturation of the spoil and the formation of lakes. Ground-water levels and lake levels indicate a connection between surface and ground water; the potentiometric surface (water level) is relatively flat, sloping gently to the west.

Water from the monitoring wells, lysimeters, and lakes at Coal City is generally less mineralized than water at Ottawa, although the range of water quality is greater (table 2). The concentrations of total dissolved solids in ground water, for example, range from 670 to 4,900 mg/L. Ground water from well no. 7 is more highly mineralized than that from the other wells and is similar in quality to ground water at Ottawa. The pH of water is more alkaline than at Ottawa and ranges from 6.6 to 8.5. Calcium and magnesium are the predominant cations, and sulfate the predominant anion. Iron is present in much smaller quantities than at Ottawa—a confirmation that there is little pyrite in the overburden.

HARRISBURG STUDY AREA

Geology

The third study area is located in southern Illinois, near Harrisburg in Saline County, and is part of a larger area that was surface mined in the 1940s and early 1950s by the Sahara Coal Company. The study area includes spoil emplaced during the early 1950s, a final cut lake, and an unmined area just north of the lake (fig. 9). The coal mined here was the Herrin (No. 6) Coal Member, which is stratigraphically higher (younger) than the No. 2 Coal (fig. 2).

The unmined overburden above the No. 6 Coal is 18 to 20 m (60 to 70 ft) thick. About 12 m (40 ft) of lacustrine silts and clays overlie 1 to 5 m (4 to 18 ft) of sand and 3 to 8 m (10 to 25 ft) of alternating beds of shale and limestone. Here, as at Coal City, most of the spoil derived from unconsolidated sediments rather than from bedrock. The lacustrine sediments are part of

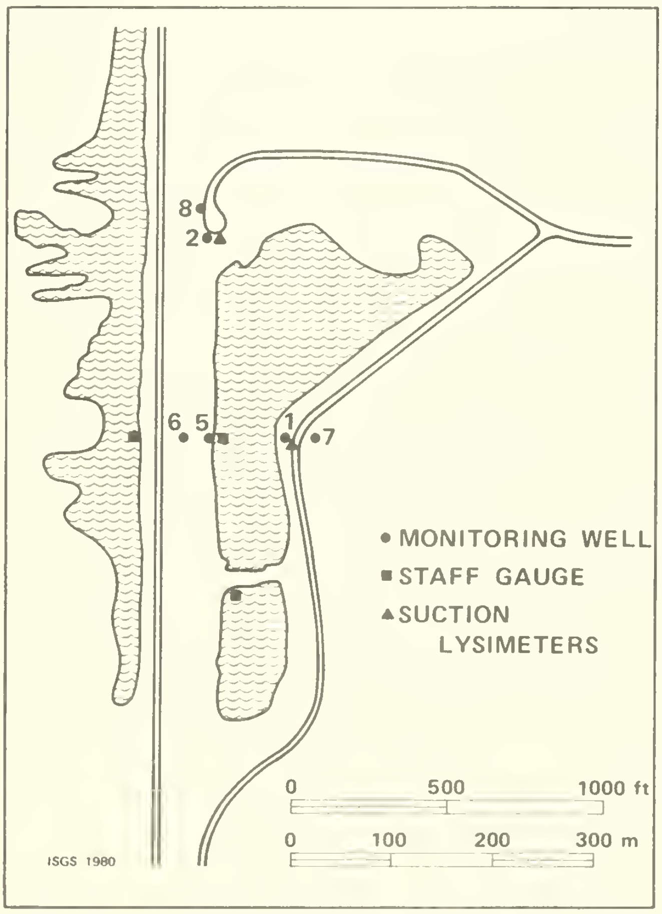

FIGURE 8. Locations of monitoring wells and instruments at Coal City study area, Grundy County (Sec. 22, T. 33 N., R. 8 E.).

TABLE 2. Water quality data for Coal City study area

Sampling point	Date sampled	T (°C)	pH	EC (µmhos/cm)	TDS (mg/L)	Alk (mg/L)	Hard (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Al (mg/L)	Ca (mg/L)	Fe (mg/L)	K (mg/L)	Mg (mg/L)	Mn (mg/L)	Na (mg/L)	Cu (mg/L)	Ni (mg/L)	Cr (mg/L)	Pb (mg/L)	Zn (mg/L)	Cd (mg/L)
Well 1	12-11-78	9	7.2	2,520	2,600	1,030	1,650	1,210	40	.24	374	54.2	17	173	2.3	184	<.01	.07	<.18	<.12	.2	<.01
Well 2	12-11-78	10	6.7	2.400	2,000	610	982	1,100	90	.24	197	<.19	37	119	.4	278	.01	.04	<.18	<.12	.01	<.01
Lake 1	12-11-78	15	7.9	835	940	100	732	630	10	.24	125	<.19	6.86	102	<.02	16.2	.02	<.02	<.18	<.12	.03	<.01
Lake 2	12-11-78	2	7.9	1,165	1,570	120	1,133	1,070	10	.24	231	<.19	12.4	135	<.02	25.8	<.01	.03	<.18	<.12	.02	<.01
Lake 3	12-11-78	3	6.9	625	880	180	651	500	11	.24	114	<.19	5.9	89	<.02	18.3	<.01	<.02	<.18	<.12	.01	<.01
Well 5	6-19-79	16.1	7.8	1,180	934	128	687	584	8	.2	131	.5	8.2	87	.19	18.9	<.09	.02	<.07	<.12	.02	<.04
Well 6	6-19-79	13.9	7.75	1,125	932	145	681	577	7	.2	120	.8	6.6	80	.25	17.1	<.09	.93	<.07	<.12	.04	.25
Well 7	6-19-79	14.9	6.65	4,550	4,900	676	2,990	2,990	20	.2	294	66	10	519	1.74	193	<.09	.04	<.07	<.12	.02	<.04
Well 8	6-19-79	17.6	7.3	1,950	1,520	250	1,160	832	49	.2	241	.4	17.2	134	.38	177	<.09	.04	<.07	<.12	.02	<.04
Lys 1	11-26-79	11.6	7.2	7,000	6,730	488	3,310	4,220	10	.3	480	.16	22	512	.04	724	.32	.12	<.08	<.17	.16	<.01
Well 1	3-18-80	10.8	7.0	800	668	379	445	58	41	<.3	105	.4	36.5	43	2.27	23.2	<.01	<.1	<.06	<.1	.069	.007
Well 2	3-18-80	12.5	8.0	1,590	1,330	467	424	434	92	<.3	80	.3	20.3	54	.29	245	<.01	<.1	<.06	<.1	.044	.007
Well 5	3-18-80	11.5	7.4	860	962	149	657	552	8	<.3	124	<.1	5.8	84	.22	18.5	<.01	<.1	<.06	<.1	.20	<.007
Well 6	3-18-80	11.2	7.4	860	918	178	632	502	6	<.3	119	<.1	6.3	81	.20	18.1	.01	<.1	<.06	<.1	.046	<.007
Well 7	3-18-80	10.5	6.6	3,100	4,910	724	3,550	3,040	18	<.3	523	55.2	8.9	520	2.25	115	.01	<.1	<.06	<.1	.10	<.007
Well 8	3-18-80	11.4	7.6	940	842	298	320	251	97	<.3	65	<.1	8.9	38	.08	165	.03	<.1	<.06	<.1	.017	<.007
Lys 1	3-18-80	9.8	7.2	1,800	*	*	1,426	*	*	<.3	402	.2	5.2	102	.05	46.8	.13	<.1	<.06	<.1	.21	<.007
Lys 2	3-18-80	8.5	6.9	4,100	6,310	495	*	4,016	10	*	*	*	*	102	.05	46.8	*	*	*	*	*	*
Lake 1	5-19-80	17.2	8.45	1,125	914	104	430	522	7	.2	113	.06	5.3	81.4	.03	14.7	<.01	<.1	<.05	<.1	.004	<.003
Lake 2	5-19-80	17.6	8.55	1,750	1,602	134	759	1,014	7	.2	204	.04	10.9	137	.06	25.8	<.01	<.1	<.05	<.1	.006	<.003
Lake 3	5-19-80	17.45	8.30	1,090	810	174	402	433	9	.2	109	.03	5.0	71.3	.04	16.2	<.01	<.1	<.05	<.1	.007	<.003
Well 5	11-18-80	15.0	7.8	980	902	174	513	491	50	<.2	98	<.04	6.2	65	.11	34	<.01	<.03	<.1	<.1	.12	<.005
Lake 1	11-18-80	14.0	7.5	1,010	900	111	595	542	21	<.2	108	.05	5.7	79	.01	16	<.01	<.03	<.1	<.1	.02	<.005
Lake 2	11-18-80	14.0	7.91	1,600	1,650	145	1,120	1,061	20	<.2	211	<.04	11.3	144	.02	29	.01	<.03	<.1	<.1	.02	<.005
Lake 3	11-18-80	14.0	7.7	860	778	169	545	422	23	<.2	101	.06	7.9	71	.03	19	<.01	<.03	<.1	<.1	.02	<.005
Lys 1	11-18-80	15.0	7.95	2,300	2,408	248	1,945	1,388	34	<.2	515	<.04	4.9	160	.03	58	.02	<.03	<.1	<.1	.13	<.005
Lys 2	11-18-80	15.0	8.0	5,000	6,562	470	3,655	4,040	44	<.2	485	.25	16.4	596	.10	418	.03	.03	<.1	<.1	.13	<.005

TABLE 2. *(continued)*

Sampling point	Date sampled	T (°C)	pH	EC (µmhos/cm)	TDS (mg/L)	Alk (mg/L)	Hard (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Al (mg/L)	Ca (mg/L)	Fe (mg/L)	K (mg/L)	Mg (mg/L)	Mn (mg/L)	Na (mg/L)	Cu (mg/L)	Ni (mg/L)	Cr (mg/L)	Pb (mg/L)	Zn (mg/L)	Cd (mg/L)
Well 2	11-21-80	17.5	7.5	1,480	1,026	357	322	356	199	<.2	63	.06	16.2	40	.19	243	<.01	<.03	<.1	<.1	.04	<.005
Well 6	11-21-80	16.0	7.75	620	491	184	328	217	32	<.2	65	.42	5.9	40	.17	13	.03	<.03	<.1	<.1	.07	<.005
Well 7	11-21-80	16.0	6.8	4,100	4,998	685	3,515	2,827	54	1.2	540	56	10.5	500	2.03	105	.19	<.03	<.1	.4	.21	<.05

*Insufficient sample for analysis.

TABLE 3. Water quality data for Harrisburg study area

Sampling point	Date sampled	T (°C)	pH	EC (µmhos/cm)	TDS (mg/L)	Alk (mg/L)	Hard (mg/L)	SO_4 (mg/L)	Cl (mg/L)	Al (mg/L)	Ca (mg/L)	Fe (mg/L)	K (mg/L)	Mg (mg/L)	Mn (mg/L)	Na (mg/L)	Cu (mg/L)	Ni (mg/L)	Cr (mg/L)	Pb (mg/L)	Zn (mg/L)	Cd (mg/L)
Well 1	6-17-80	18	7.3	3,000	2,770	299	1,700	1,730	21	<.3	334	0.2	11.3	211	1.3	200	.01	<.05	<.06	<.05	.07	<.003
Well 2	6-17-80	16	6.95	1,620	1,390	345	840	660	55	<.3	212	0.7	2.3	75	2.1	152	.01	<.05	<.06	<.05	.22	<.003
Well 3	6-17-80	19	7.18	3,300	3,060	328	1,850	1,890	30	<.3	362	2.4	10.5	227	1.5	211	.01	<.05	<.05	<.05	.25	<.003
Well 4	6-17-80	17	7.1	1,450	1,260	362	730	530	93	<.3	190	3.7	3.3	61	.6	162	.01	<.05	<.06	<.05	.03	<.003
Well 5	6-18-80	15.5	6.52	4,900	4,760	243	2,510	3,010	52	<.3	486	2.5	6.7	311	8.3	457	.02	<.05	<.06	<.05	.18	<.003
Well 6	6-18-80	15	6.88	5,000	4,740	232	2,410	3,030	55	<.3	458	1.5	9.7	305	3.8	533	.02	<.05	<.06	<.05	.26	<.003
Well 7	6-18-80	15.5	6.61	4,600	4,900	207	2,390	3,040	55	<.3	470	.6	8.6	293	6.5	541	.02	<.05	<.06	<.05	.26	<.003
Lys 1	6-17-80	25	3.75	*	*	*	32,700	*	*	209	370	14,600	8.6	782	1,070	203	.14	.64	<.06	<.32	5.45	NM
Lake 1	6-18-80	24.3	7.47	5,350	5,070	192	2,400	3,100	52	<.3	452	.2	10.2	308	1.9	511	.02	<.05	<.06	<.05	.05	<.003
Well 1	10-30-80	17	7.25	3,400	2,976	322	1,609	1,727	39	.3	320	1.6	11.8	195	1.2	224	.01	<.03	<.1	.1	.55	<.005
Well 2	10-30-80	18	7	2,200	1,448	380	898	626	74	.4	218	3.9	2.9	83	1.5	181	<.01	<.03	<.1	.1	.42	<.005
Well 3	10-30-80	16	7	3,700	3,370	320	1,881	1,971	54	.5	373	3.4	9.9	228	1.7	248	.01	<.03	<.1	.1	.32	<.005
Well 4	10-30-80	16	7	2,300	1,452	483	827	589	106	.6	205	3.3	3.5	74	.9	183	<.01	<.03	<.1	.1	.46	<.005
Well 5	10-30-80	13.5	6.9	4,700	4,912	248	2,522	2,995	77	.8	493	5.5	7.2	307	7.9	495	.04	<.03	<.1	.4	.37	<.005
Well 6	10-30-80	18	7.1	5,300	5,174	249	2,322	3,140	78	.4	455	2.5	10.5	285	3.2	551	.01	<.03	<.1	.3	.39	<.005
Well 7	10-30-80	16	7.1	5,100	5,112	286	2,236	3,018	81	.4	448	1.1	9.7	268	5.3	544	<.01	<.03	<.1	.1	.51	<.005
Lake 1	10-30-80	16.5	7.1	5,300	5,196	205	2,349	3,099	121	.4	457	.9	11.3	292	1.3	608	.03	<.03	<.1	.2	.20	<.005

*Insufficient sample for analysis.
NM = not measured.

an extensive Wisconsinan (late Pleistocene) deposit (Frye et al., 1972). The Herrin Coal was 1.5 to 2 m (5 to 6 ft) thick in this area and overlay 1 to 2 m (3 to 6 ft) of underclay (Smith, 1957). More than 400 m (1,300 ft) of Pennsylvanian shales, sandstones, limestones, and coals underlie the No. 6 Coal at this site.

Spoil thickness ranges from about 18 to 24 m (60 to 80 ft). The spoil is predominantly fine-grained silt and clay. Boulders of limestone and shale up to 1 m (3 ft) in diameter appear on the surface and presumably are also incorporated into the spoil. Even though the area was not reclaimed after mining, vegetation has become established on the mine spoil. Here, as at the Coal City site, lakes have formed in the spoil owing to the low hydraulic conductivity of the underlying rocks.

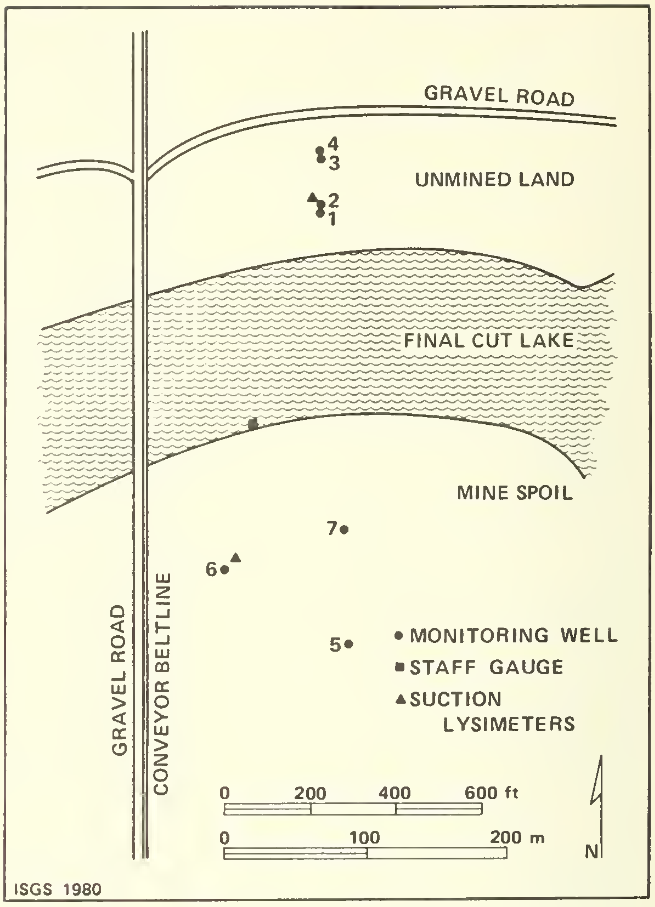

FIGURE 9. Locations of monitoring wells and instruments at Harrisburg study area, Saline County (Sec. 21, T. 9 S., R. 5 E.).

Ground water

Monitoring wells, lysimeters, and tensiometers were installed in mine spoil and undisturbed geologic materials to determine the effect of mining on ground water in this area (fig. 9). Four wells were drilled in unmined overburden—wells 2 and 4 to the base of the glacial drift, and wells 1 and 3 to the top of the No. 6 Coal. Wells 5, 6, and 7 were drilled to the base of the spoil. The water levels in these wells suggest the hydraulic continuity of ground water with the final cut lake.

Ground water in the spoil is slightly acidic and highly mineralized, even though there is little visible evidence of pyrite in the spoil (table 3). Ground water in the spoil is similar to ground water found in spoil at the other two sites—sulfate is the predominant anion, and calcium, magnesium, and sodium are the major cations. Sodium concentrations are high at this site, although they are low at Ottawa and range from low to high at Coal City. Ground water in the undisturbed overburden north of the lake is much less mineralized than ground water in the spoil; this suggests that surface mining caused no deterioration of quality in near-surface ground waters outside the mine.

DISCUSSION

The geology of a site controls the character of the spoil and the behavior of the ground water. Both the overburden and underlying bedrock can affect ground-water and surface-water hydrology.

At the Ottawa site, mining has undoubtedly altered both the surface- and ground-water movement. Surface water can now leave the site at a lower elevation than

TABLE 4. Summary of water quality at 3 study sites

					Off-site wells	
Site	Parameter	Spoil wells	Lysimeters	Lakes	Drift	Bedrock
Ottawa						
	pH	6-6.7	3.6-6.0			
	EC (μmhos)	3,400-4,000	NM			
	TDS (mg/L)	3,800-5,500	8,000-11,000			
	$SO_4^=$ (mg/L)	2,450-3,750	NM			
	Fe (mg/L)	12-400	500-1,400			
	Ca (mg/L)	400-600	320-430			
	Mg (mg/L)	350-750	600-1,500			
	Na (mg/L)	9-100	180-1,090			
Coal City						
	pH	6.7-8.0	6.9-8.0	6.9-8.6		
	EC (μmhos)	800-4,600	1,800-7,000	625-1,750		
	TDS (mg/L)	490-5,000	2,400-6,700	500-1,650		
	$SO_4^=$ (mg/L)	60-3,000	1,400-4,200	420-1,100		
	Fe (mg/L)	<.04-66	<.04-.25	<.2		
	Ca (mg/L)	60-540	400-515	100-250		
	Mg (mg/L)	40-520	100-600	70-145		
	Na (mg/L)	13-280	47-725	15-29		
Harrisburg						
	pH	6.5-7.1	3.8	7.1-7.5	6.9-7.1	7.0-7.3
	EC (μmhos)	4,600-5,300	NM	5,300-5,350	1,450-2,300	3,000-3,700
	TDS (mg/L)	4,740-5,175	NM	5,100-5,200	1,250-1,450	2,760-3,370
	$SO_4^=$ (mg/L)	3,000-3,140	NM	3,100	530-660	1,730-1,970
	Fe (mg/L)	.6-5.5	14,600	.2-.9	.7-3.9	.2-3.4
	Ca (mg/L)	450-490	370	450-460	200-220	320-373
	Mg (mg/L)	270-310	780	290-310	60-83	195-230
	Na (mg/L)	450-550	200	510-610	150-185	210-250

NM = not measured.

prior to mining. It is likely that ground water always drained from the overlying shale and glacial drift into the underlying St. Peter Sandstone, which is unsaturated in its upper part and has a high (saturated) hydraulic conductivity. However, now there is only spoil and thin underclay above the sandstone. As a result, the static water level is near the base of the spoil rather than near the surface. It is likely that, in consequence, acidification occurs by oxidation reactions in the unsaturated spoil; the ground water moving (by saturated or unsaturated flow) through the spoil therefore becomes acidic and highly mineralized. Undoubtedly, surface-water runoff is also acidic and mineralized.

At both the Coal City and Harrisburg mines, unconsolidated sediments compose the major portion of the overburden and resulting spoil. The unconsolidated sediments are low in pyrite. At Coal City, where the spoil is almost entirely sand, ground water is mineralized but less so than at Ottawa. Lacustrine silts and clays are the predominant spoil materials at Harrisburg; some fragmented shale and limestone are also present. Ground water is acidic and highly mineralized, even though there is little visible evidence of pyrite in the spoil. At the Coal City and Harrisburg sites, a thick succession of predominantly fine-grained materials beneath the coal prevents drainage. Consequently, by comparison with the spoil at the Ottawa site, a relatively large proportion of the spoil at these two sites is saturated. The ground-water flow systems at these two sites probably are also relatively unaltered by mining.

The thick successions of fine-grained bedrock found beneath the coal at Coal City and Harrisburg occur over much of Illinois; thin successions overlying

more permeable rocks—such as are found at the Ottawa site—are much less common. As compared with mining at sites like that at Ottawa, surface mining in much of Illinois should effect little change in the physical characteristics of ground-water flow systems.

The major effect of surface mining on ground water at all sites is deterioration of water quality (data for the three sites are summarized in table 4). Deterioration is obvious at Harrisburg, where surface water from the lake and ground water from the monitoring wells in the spoil are more acidic and mineralized than ground water from wells in the undisturbed drift and bedrock. Although there is no information on ground-water quality for unmined portions of the Ottawa and Coal City sites, ground water from the spoil is more mineralized than is usual for undisturbed overburden. The deterioration of quality is due to interactions between spoil and ground water, some of which are not fully understood. Where pyritic material is present on the surface and throughout the spoil, weathering of pyrite has produced acidic spoil; ground and surface waters are acidic and highly mineralized. Acidification may be enhanced at sites where a large proportion of the spoil is not saturated with water, as at Ottawa.

The three sites were mined prior to the enactment of reclamation laws in Illinois. Reclamation of the sites, including proper handling of the pyritic material to minimize oxidation, would probably have reduced adverse impacts on ground and surface waters.

The work to date has demonstrated that the geology of any site must be understood if the impact of mining on geologic materials and ground water is to be properly evaluated. Future work will include more detailed study of the physical and chemical characteristics of ground-water flow systems. In addition to research in and around abandoned mines, long-term studies are needed prior to, during, and subsequent to mining.

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APPENDIX: Logs of Borings

OTTAWA

Well #1	0-2.1 m (0-7 ft) silty clay, 2.1-9.0 m (7-29.5 ft) weathered shale, 9.0-9.1 m (29.5-30 ft) silty clay till. No casing data available.
Well #2	10 m (33 ft) deep. No log or casing data available.
Well #3	0-9.9 m (0-32.5 ft) weathered shale, 9.9-10.4 m (32.5-34 ft) dense black coal, 10.4-11.3 m (34-37 ft) dense sandy shale. No casing data available.
Lysimeters near 3	Three at depths of 8.1 m (24.5 ft), 5.9 m (19.5 ft), and 2.8 m (9.3 ft).
Well #4	12.2 m (40 ft) deep. No log or casing data available.
Well #5	9.1 m (30 ft) deep. No log or casing data available.
Well #6	0-12.2 m (0-40 ft) alternating layers (6) of silty clay and shale.

COAL CITY

Well #1	0-13.7 m (0-45 ft) mostly medium- to coarse-grained sand, with some clay layers and pebbly till layers. Coal lump at 3.5 m (11.6 ft). Shale bedrock at 13.6 m (44.5 ft), cased to bedrock.
Lysimeters near 1	Destroyed before any samples obtained, 2.7 m (9.1 ft) and 1.3 m (4.2 ft) deep.
Well #2	0-18.6 m (0-61 ft) mostly medium- to coarse-grained sand, with some clay layers, massive till layers, and thin coal layers. Shale bedrock at 18.4 m (60.2 ft). No details on casings given.
Lysimeters near 2	Depths of 2.8 m (9.3 ft) and 1.2 m (3.9 ft).
Well #5	0-6.9 m (22.5 ft) fine to coarse sand, with coarseness increasing with depth, 6.9-8.2 m (22.5-27 ft) layers of massive till, silty clay, and sandy silt, 8.2-8.4 m (27-27.5 ft) weathered shale. Cased to top of weathered shale.
Well #6	0-8.1 m (0-26.5 ft) fine- to coarse-grained sand, increasing in size with depth, 8.1-9.0 m (26.5-29.5 ft) clay, 9.0-9.3 m (29.5-30.5 ft) shale. Cased to 7.95 m (26.0 ft).
Well #7	0-13.7 m (0-45 ft) mostly layers of silty sand to very coarse sand, also some layers of clay and clayey till, 13.7-14.0 m (45-46 ft) black coal and shale. Cased nearly to the base.
Well #8	0-13.7 m (0-45 ft) silty sand to medium-grained sand with a gravel layer at 10.4 m (34 ft), 13.7-14.0 m (45-46 ft) black coal and shale. Cased to 13.85 m (45.5 ft).

Well #1	0-11.0 (0-36 ft) clay, 11.0-12.8 m (36-42 ft) sand, 12.8-14.0 m (42-46 ft) gray shale, 14.0-16.5 m (46-54 ft) sandstone, 16.5-19.8 m (54-65 ft) limestone, 19.8-20.4 m (65-67 ft) black slate, 20.4-20.7 m (67-68 ft) #6 Coal. Cased to 20.1 m (66 ft).
Well #2	0-14.3 m (0-47 ft) virtually identical to well #1. Finished in gray shale at 14.3 m (47 ft). No casing data available.
Lysimeters near 2	Two at depths of 4.3 m (14 ft) and 2.4 m (8 ft).
Well #3	0-12.2 m (0-40 ft) clay, 12.2-16.8 m (40-55 ft) sand, 16.8-17.7 m (55-58 ft) gray shale and slate, 17.7-19.5 m (58-64 ft) limestone, 19.5-20.1 m (64-66 ft) #6 Coal. Cased to 19.8 m (65 ft).
Well #4	0-17.7 m (0-58 ft) essentially the same as well #3. Finished in gray shale. Cased to 14.3 m (47 ft) into sand.
Well #5	0-3.0 m (0-10 ft) shale fragments, 3.0-7.6 m (10-25 ft) silt to silty clay, 7.6-12.2 m (25-40 ft) gray shale, 12.2-16.8 m (40-55 ft) silty clay to clayey silt, 16.8-18.3 m (55-60 ft) shale and limestone fragments, 18.3-22.1 m (60-72.5 ft) silty clay to silt. No casing data available.
Well #6	0-1.5 m (0-5 ft) rock fragments, 1.5-3.0 m (5-10 ft) brown clay with pebbles, 3.0-4.6 m (10-15 ft) silty clay, 4.6-18.6 m (15-61 ft) no log, 18.6-18.0 m (61-62 ft) shale. Cased to 18.6 m (61 ft).
Lysimeters near 6	Two at 4.5 m (15 ft) and 2.7 m (9 ft) deep.
Well #7	62 ft deep, no log or casing data.